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EFFECT OF SUBDUCTION OF THE MENDOCINO FRACTURE ZONE ON TERTIARY SEDIMENTATION IN SOUTHERN CALIFORNIA

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ABSTRACT

Glazner, A.F., and Loomis, D.P., 1984. Effect of subduction of the Mendocino fracture zone on Tertiary sedimentation in southern California. Sediment. Geol., 38: 287–303.

The age and paleogeographic setting of middle to late Tertiary fluvial deposits in southern California are consistent with the theory that subduction of the Mendocino fracture zone produced a north-facing, north-moving slope and zone of deformation in the North American plate. The Mendocino fracture zone was a 1 km high, north-facing scarp in the Farallon plate that moved northward at about 3 cm yr^{-1}. Subduction of this scarp produced isostatic stress in the overlying North American plate. If this stress were expressed in the crust as a north-facing slope, then a given area should have experienced the following sedimentary evolution: (1) normal (probably oceanward) drainage when the slope was far to the south; (2) reorientation to northward drainage as the slope moved to a position immediately south of the area; (3) deposition of coarse sedimentary units, possibly accompanied by down-to-the-north faulting, when the slope reached the area; (4) uplift, deformation, and erosion of previously deposited sediments as the area was uplifted along the slope; and (5) reestablishment of normal drainage. Compilation of data from sedimentary sequences in southern California supports this model. In particular, the time of fracture-zone passage was marked by strong dominance of northward stream flow. These relationships suggest that middle Tertiary fluvial sedimentation in the southern California area was strongly influenced by passage of the fracture zone.

INTRODUCTION

Recent studies of the Tertiary geology of the southwestern United States have demonstrated that most volcanism and much faulting in that area occurred during or after the tectonic reorganization that accompanied the termination of subduction at the California coast in the late Oligocene and Miocene (Atwater, 1970; Dickinson and Snyder, 1979a, b; Shafiqullah et al., 1980; Glazner, 1981a). Plate-tectonic reconstructions indicate that first contact between the Pacific and North American plates occurred 25–30 m.y. ago off the coast of southern California or northern Mexico (Fig. 1). This contact resulted in the formation of two triple junctions, the

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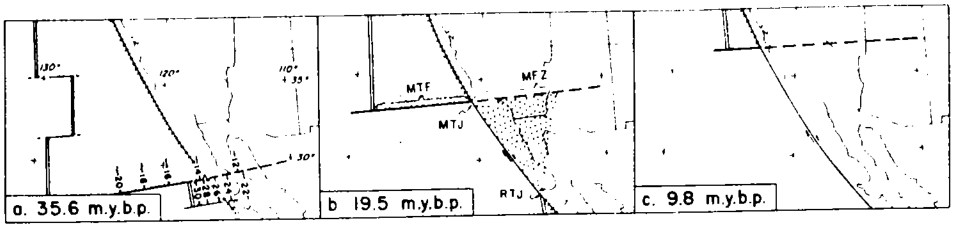

Fig. 1. Plate boundaries and calculated position of the Mendocino fracture zone (*MFZ*) at 35.6, 19.5 and 9.8 m.y. ago, superimposed on a map of western North America. Double line indicates Pacific–Farallon spreading ridge; solid line indicates the Mendocino transform fault (*MTF*); dashed line indicates *MFZ*; crossed line indicates trench (drawn along the continental slope). Farallon plate is shown by dash pattern. Isobaths on the Farallon plate represent calculated elevation of the sea floor, in hundreds of meters, above an abyssal depth of 6 km (Glazner, 1981a). V-pattern in b represents the approximate position of the slab window postulated by Dickinson and Snyder (1979b); omitted from c.

Mendocino and Rivera, that migrated north and south, respectively, relative to the North American plate. Recent models for the tectonic evolution of California, Arizona, and Nevada have tied geologic events on land to the northward migration of the Mendocino triple junction (Atwater, 1970; Christiansen and Lipman, 1972; Lipman et al., 1972; Snyder et al., 1976; Blake et al., 1978; Dickinson and Snyder, 1979a). These models predict that a given area should have experienced subduction-type volcanism in the early and middle Tertiary, followed by a switch to bimodal, extensional-type volcanism and extensional basin-fill sedimentation in the later Tertiary, after the Mendocino triple junction moved north past a given area.

Glazner (1981a) noted that major episodes of volcanism and faulting in the southwestern United States correlate with the time that the subducted Mendocino fracture zone passed under a given area. The Mendocino fracture zone was a major (1 km high) topographic step in the subducted Farallon plate, because crust on its south side was 30 m.y. younger than crust on its north side (Fig. 1a). Isostatic

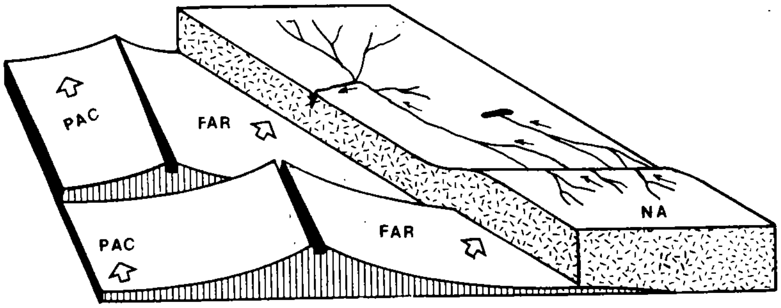

Fig. 2. Diagrammatic illustration of subduction of a fracture zone. This diagram is equivalent to a view looking north along the California coast at the time of Fig. 1a. Arrows give the directions of motion of the oceanic plates relative to the North American plate. *PAC* = Pacific plate, *FAR* = Farallon plate, *NA* = North American plate.

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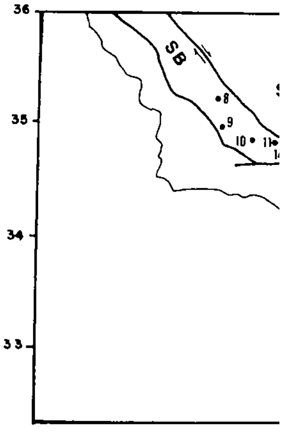

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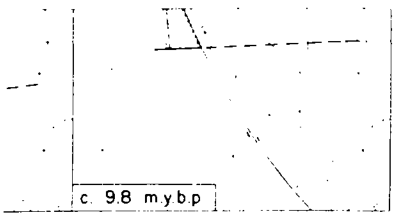

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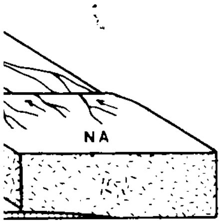

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balance predicts that subduction of this step should have produced a flexure in the overlying North American plate; the amount of flexure of the plate should have been about 70% of the vertical offset on the subducted Mendocino fracture zone, or about 700 m (Glazner, 1981a). If the flexural rigidity (Turcotte, 1979) of the plate was low enough, then this flexure could have been expressed in the crust as a north-facing slope that moved northward at about 3 cm yr^{-1} (Fig. 2). If such a slope existed in the Tertiary, it would have had a profound effect on fluvial sedimentation in the southwestern United States.

In this paper we test the hypothesis that a north-facing, northward-moving slope moved across the southwestern United States in late Oligocene and Miocene time. Our approach is based on a compilation of data from the literature, supplemented by our own observations in the Mojave Desert. These data strongly support the theory of a north-facing, northward-migrating slope.

METHOD AND AREA OF STUDY

For this study we compiled data on sedimentary sequences in southern California. The geographic coverage of our study is shown in Fig. 3. This is the only area in the southwestern United States for which detailed information is available for many basins.

Paleocurrent determinations discussed below are based mainly on quantitative statistical studies of sedimentary structures or on provenance studies. Some determinations which were not quantitatively presented were included for better geographic coverage. The interested reader is referred to the original papers for discussions of the methods employed in these determinations.

Plate reconstructions were derived using the rotation parameters of Molnar and

Fig. 3. Index map for sedimentary data in this study. Sedimentary sequences *1–14* are identified in Fig. 6. *MB* = Mojave block; *TR* = Transverse Ranges; *SB* = Salinian block; *SJ* = San Joaquin Basin; *SN* = Sierra Nevada. Faults: *SAF* = San Andreas fault; *GF* = Garlock fault.

Stock (1981, and P. Molnar and J. Stock, pers. commun., 1981), which are based on studies of marine magnetic anomalies. Possible uncertainties in these reconstructions are large; however, the close correspondence shown between the predicted position of the Mendocino fracture zone and geologic events in the southwestern United States (Glazner, 1981a; Glazner and Supplee, 1982) suggests that the rotation parameters accurately reflect the location of the Mendocino fracture zone. Further study and refinement of the data on land will help to constrain the plate reconstructions.

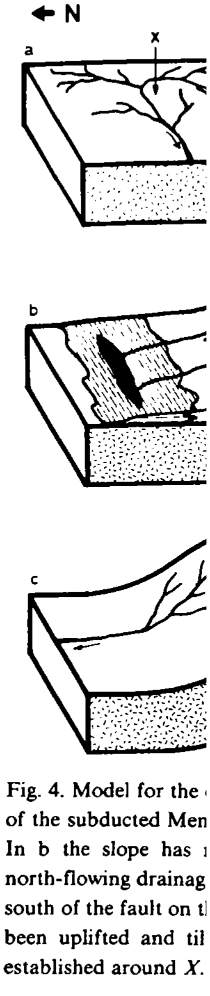
PALINSPASTIC RECONSTRUCTIONS

The plate reconstruction used in this paper gives relative motions between the Pacific and North American plates. Therefore, in order to study the relationship between sedimentation and plate movements, we must restore the basins to their positions relative to the North American continent at the time of deposition. Because our data is summarized in a latitude vs. age plot, this restoration is critical for basins that lie west of the San Andreas fault and have probably been moved northwestward hundreds of kilometers since the early Miocene. The palinspastic reconstruction used here is the one given by Bohannon (1975; see also Nilsen, 1984, this volume) and is based on similarities between mid-Tertiary rocks in the Orocopia Mountains, southern Salinian block, and San Gabriel Mountains. Late Tertiary basin-range extension in an east–west direction (Stewart, 1978; Wernicke et al., 1982) does not significantly affect latitude-age considerations and was not included in the reconstruction.

A complicating factor in the interpretation of paleocurrent directions is the possibility that structural blocks have been rotated since deposition of the pertinent sediments. Luyendyk et al. (1980) found that many blocks in the western Transverse Ranges have been rotated 90° or more since the middle Miocene, presumably in response to right-lateral shear imposed by the San Andreas fault system. However, measured rotations in the basins considered in this study are small or nonexistent (Luyendyk et al., 1980, fig. 1; Terres et al., 1981; Terres, 1982), so measured paleocurrent data should accurately reflect late Oligocene–early Miocene transport directions. If future paleomagnetic work demonstrates large rotations for these basins, then some of the conclusions of this paper may have to be modified.

TECTONIC MODEL

If the Mendocino fracture zone was expressed in the crust of southern California as a substantial north-facing, north-moving slope in the late Oligocene and early Miocene, then basins and fluvial systems should have followed the evolution shown in Fig. 4. This figure shows the evolution of a single area and how passage of the



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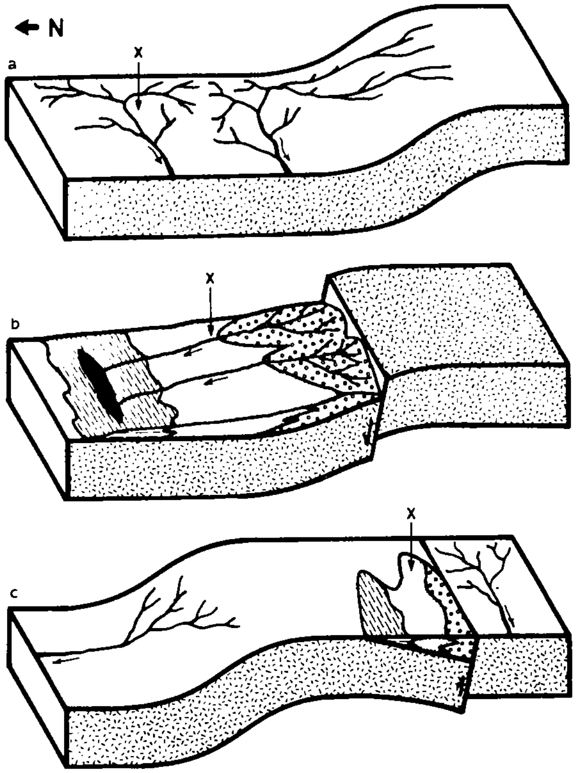

Fig. 4. Model for the evolution of sedimentation at a given point *X* in southern California during passage of the subducted Mendocino fracture zone. In a the slope is far enough south of *X* that no effect is seen. In b the slope has moved under *X* and some down-on-the-north faulting has occurred, producing north-flowing drainage and a general northward decrease in the coarseness of sediments. Stippled pattern south of the fault on the top surface of the block indicates uplifted, eroding basement terranes. In c, *X* has been uplifted and tilted as the slope moved to the north. Westward drainage has once again been established around *X*.

fracture zone would have affected the sedimentary history and drainage patterns of that area.

Consider the point given by X in Fig. 4. When the fracture zone was far to the south of this area (Fig. 4a), drainage around X was unaffected by the fracture zone. In general one would expect an integrated system of westward drainage, toward the coast. However, as the fracture zone moved to a position closer to X the drainage system around X would begin to show dominance of northerly stream flow (Fig. 4b). If X was not in a sedimentary basin before approach of the slope, northward-prograding fluvial sediments would be deposited on an earlier erosion surface; if it was in a basin before approach of the slope, deposition of south-derived sediments would begin, perhaps with topographic modification of the basin. Northward movement of the slope would bring source areas closer to X, causing sediments at X to coarsen. If the crust failed by normal faulting during passage of the slope, coarse breccias, conglomerates, and landslide deposits would form at the bases of the fault scarps (Fig. 4b). Eventually X would be uplifted by the northward-moving slope as young lithosphere south of the Mendocino fracture zone in the subducted Farallon plate moved under X. Faulting and tilting of the sediments could occur as the slope moved under the basin. After X reached the top of the slope rocks there would be eroded and possibly redeposited, and a west-flowing stream system could again be established (Fig. 4c).

To summarize, this model predicts that a given area would experience the following sequence of events during passage of the slope associated with the Mendocino fracture zone: (1) shift to north-flowing drainage or north-facing depositional slopes; (2) coarsening of sedimentation, perhaps with deposition of coarse conglomerates, breccias, and landslide deposits derived from north-facing scarps: (3) faulting and tilting of the sedimentary sequence; and (4) uplift and erosion of the sequence. The time required to complete this series of events depends on the north–south extent of the slope. The slope moved north at about 3 cm yr^{-1}, so if the north–south width of the slope was, for example, 100 km, the above series of events should have taken about 3 m.y. to complete in any given area.

A crucial part of the model is that later erosion would remove many of the sediments deposited during passage of the slope. Thus, much of the evidence of Mendocino fracture zone motion would be destroyed by the very process that produced it, resulting in an unconformity at the predicted time of passage (Fig. 4). However, preservation of the pertinent sequences could be achieved in a number of ways, most notably by local isostatic loading and depression of the crust caused by accumulation of thick basin-fill deposits.

TERTIARY SEDIMENTATION IN SOUTHERN CALIFORNIA

Early Tertiary

During the Paleogene, regional drainage in the southwestern United States east of the Mojave block was to the north or northeast (Nilsen and McKee, 1979). The switch to the current pattern of south and west drainage via the Colorado and other rivers did not occur until late Miocene time (Cole and Armentrout, 1979).

Pre-Oligocene–Tertiary sedimentary rocks are present in areas bordering the Mojave block, including the Transverse Ranges, the Salinian block, the San Joaquin basin, the southern Sierra Nevada, and the El Paso Mountains. There are no recognized Paleocene or Eocene rocks in the Mojave block, and only the latest Oligocene is represented there. During this time the Mojave block was a positive area with external drainage, and shed large volumes of detritus to basins to the south and west (Reed, 1933; Hewett, 1954; Nilsen, 1977). Marine basins in the present Transverse Ranges and Salinian block opened westward into deep water, as did the

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marine San Joaquin basin, which received sediments from the Sierra Nevada (Nilsen and Clarke, 1975). Turbidite facies in coastal basins and the San Joaquin basin coarsen to the east (Bartow, 1973; Nilsen and Clarke, 1975), indicating west-facing submarine slopes. Small intermontane basins between the Sierra Nevada and Mojave blocks were filled with fluvial deposits (Goler Formation) transported by west- and south-flowing streams (Cox, 1982).

Oligocene–early Miocene

The Mendocino triple junction first met the trench off western North America in the middle Oligocene at the latitude of northern Mexico (Fig. 1). By 25 m.y. ago the Mendocino fracture zone was at the latitude of southern California, moving north at around 3 cm yr^{-1}.

Major paleogeographic changes took place late in Oligocene time. Continental and marine basins were uplifted and tilted, and early Tertiary sequences were bevelled by erosion. Late Oligocene alluvial-fan and fluvial facies prograded over this erosion surface in coastal and inland basins surrounding the Mojave block. In classical California stratigraphy (e.g. Reed, 1933) an Oligocene regression is recognized. The shift from marine to nonmarine conditions in coastal California occurred early in the Oligocene and roughly coincides with a global eustatic sea-level drop at 30 m.y. (Vail and Hardenbol, 1979; Nilsen, 1984, this volume). In the Mojave block, the apparent early Tertiary hiatus ended 22–24 m.y. ago with the beginning of widespread continental deposition. The previous external drainage system was destroyed as the block was broken into numerous small basins with internal drainage. In the eastern Mojave block, volcanic, fluvial and lacustrine facies of the early Miocene Hector Formation were deposited on deeply eroded Mesozoic basement rocks (Woodburne et al., 1974; Miller, 1978; Moseley, 1978). In the central Mojave block, the onset of sedimentation is represented by fluvial deposits and megabreccias of the Pickhandle Formation (Fig. 5a; McCulloh, 1952). Dibblee (1968) noted that the Pickhandle breccias were locally derived and that their deposition was probably tectonically triggered. Their direction of transport is unknown.

Sedimentologic data for Oligocene–Miocene time in southern California is summarized in Fig. 6 (sections were chosen for this figure on the basis of availability of isotopic or biostratigraphic dates and availability of paleocurrent data; some areas with less than complete data were included to fill geographic holes). This plot of latitude vs. age shows that late Oligocene–early Miocene sedimentation in southern California was marked by a dominance of northward paleocurrents, as predicted by the fracture-zone model. This episode of northward drainage represents a departure from the westward (oceanward) drainage that apparently preceded it, at least in some areas, and also followed it in the late Miocene. Northward paleocurrents cluster around the time of passage of the fracture zone, which is shown in Fig. 6 by

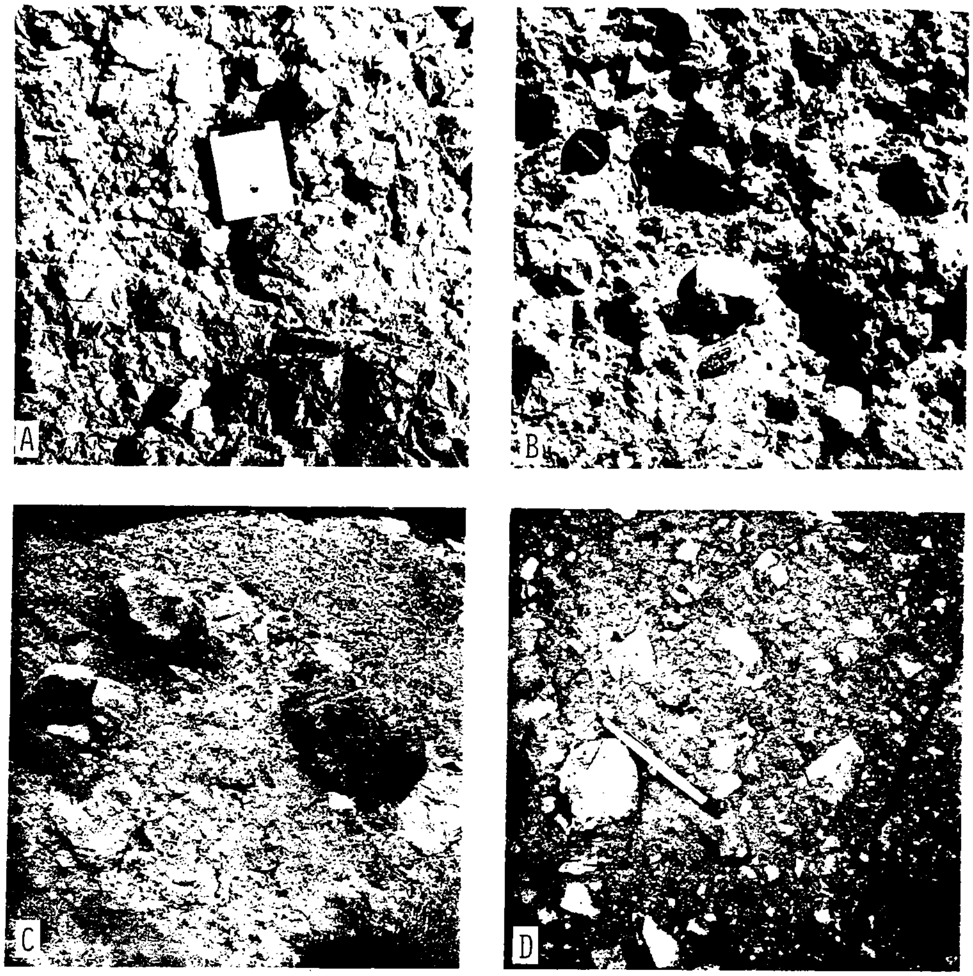

Fig. 5. Coarse early Miocene sedimentary rocks from southern California. A. Quartz monzonite megabreccia in Owl Canyon, Mud Hills, central Mojave Desert. These deposits occur as lenses, up to 200 m or more thick, within conglomerates of the early Miocene Pickhandle Formation. Individual lenses comprise shattered blocks of quartz monzonite or white felsite with essentially no matrix material. Clipboard for scale. B. Poorly sorted, coarse conglomerate of the lower Ricardo Formation, El Paso Mountains. Paleocurrent indicators show that the lower Ricardo was deposited by north-flowing streams. Lens cap for scale. C. Poorly sorted, extremely coarse conglomerate of the Vasquez Formation, Soledad basin. Largest boulder is approximately 1 m across. These rocks are inferred to have been deposited at the bases of north-facing fault scarps. D. Poorly sorted mudflow breccia from the Box Canyon area, northeastern Rodman Mountains, central Mojave Desert. These deposits consist of subangular blocks of granitic rocks in a red, sandy matrix, and were deposited on top of an early Miocene volcanic section at the base of a north- to northwest-facing fault scarp.

the diagonal line. In addition, the time swath of the fracture zone lies within or near unconformities in several places, as predicted by the model of Fig. 4.

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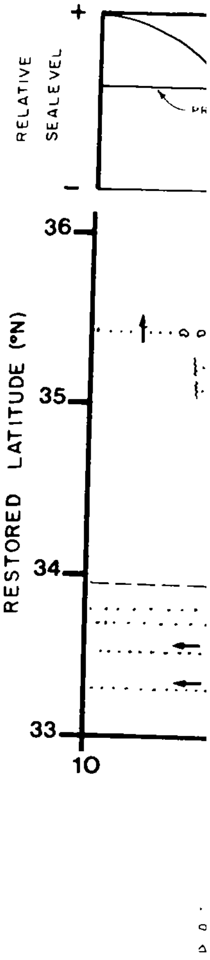

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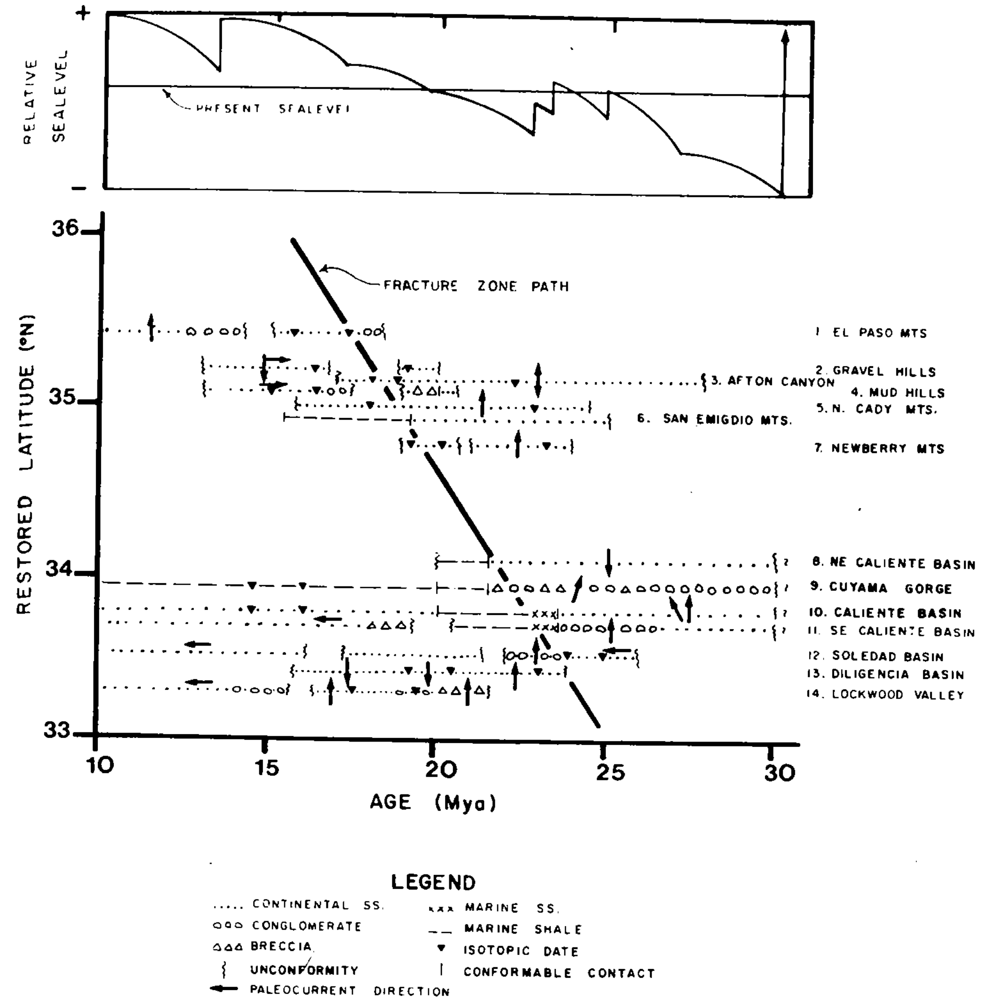

Fig. 6. Latitude vs. age plot of sedimentologic data from southern California. The latitudes given are palinspastic latitudes relative to the North American plate. This figure is essentially a correlation chart turned on its side, and shows the relationship of sedimentary sequences and paleocurrent directions to the position of the Mendocino fracture zone (diagonal line) calculated from Molnar and Stock (1981). Sea-level curve from Vail and Hardenbol (1979). Locations of sedimentary sequences *1–14* are shown in Fig. 3. *1* = El Paso Mountains; *2* = Gravel Hills; *3* = Afton Canyon; *4* = Mud Hills; *5* = northern Cady Mountains; *6* = San Emigdio Mountains; *7* = Newberry Mountains; *8* = northwest Caliente Range; *9* = Cuyama Gorge; *10* = southeast Caliente Range; *11* = Cuyama Badlands; *12* = Soledad basin; *13* = Orocopia basin; *14* = Lockwood Valley. Data compiled from Buwalda (1954), Durham et al. (1954), Hill et al. (1958), Muehlberger (1958), Carman (1964), Vedder and Brown (1968), Whistler (1969), Bartow (1973; 1978), Vedder (1973), Bohannon (1975), Woodburne (1975), Miller (1978), Moseley (1978), Dokka (1980), Blake (1982), Ehlert (1982), Woodburne et al. (1982), D.P. Loomis (in prep.).

La Honda basins. We did not include these basins in Fig. 6 because of uncertainties in their reconstructed positions.

The regional dominance of northward drainage in Oligocene and early Miocene continental units is striking. Many of the fluvial strata deposited during this time interval show only northward transport (Ricardo Formation, El Paso Mountains, Fig. 5b; Hector Formation, northern Cady Mountains; Simmler Formation, Cuyama Valley) suggesting that they were deposited on north-facing paleoslopes in one-sided basins. Coarse breccias of southern provenance were deposited in the Plush Ranch, Vasquez, and Simmler Formations immediately north of east–west faults, indicating syndepositional, down-to-the-~~north faulting.~~ Crowell (1968) showed that many east–west trending strike-slip faults in the Transverse Ranges showed a period of down-to-the-north dip-slip in late Oligocene or early Miocene time, before their later strike-slip reactivation as part of the San Andreas fault system. These relations suggest that many of these east–west faults, which in large part define the grain of the Transverse Ranges, formed in the late Oligocene and early Miocene as the crust flexed and fractured above the subducted fracture zone.

That other basins may have been east–west grabens is suggested by the occurrence of both north and south paleocurrent indicators in the Diligencia Formation (Spittler and Arthur, 1982), Hector Formation at Afton Canyon (Moseley, 1978), and earliest Plush Ranch Formation (Carman, 1964; Bohannon, 1975). None of the continental basins investigated here had significant eastward or westward drainage during the late Oligocene or early Miocene.

A pattern of northward progradation can also be established in basins which remained marine during the late Tertiary, but this pattern is somewhat obscured by sea-level rise following the late Oligocene lowstand (Vail and Hardenbol, 1979). In the San Joaquin basin, the mouth of the Kern River shifted north 15 km along the western flank of the Sierra Nevada (MacPherson, 1978), causing the main depocenter for the Mohnian Stevens sands to shift northward. This change took place as the basin was tectonically uplifted several hundred meters during the time of Mendocino fracture zone passage (Loomis and Glazner, 1982). In the Salinian block, fluvial rocks of the Simmler Formation are succeeded by and interfinger with the marine Vaqueros Formation (Bartow, 1973). The Simmler depositional basin connected with the open ocean, and its terrestrial environments were flooded as sea level rose in the early Miocene. Turbidites in deep-water facies of the Vaqueros indicate deepening to the west as might be expected, but the base of the Vaqueros on the Simmler is older in the south than in the north (Bartow, 1973, 1978).

Late Miocene

A second major paleogeographic change occurred in middle to late Miocene time. Oligocene–early Miocene continental sequences were uplifted, eroded and overstepped by finer-grained continental or marine rocks, typically deposited on west-facing paleoslopes. This return to westward transport effectively brackets the brief interval of northward drainage within a much longer period of westward drainage.

This uplift is marked in the central Mojave block by a widely exposed unconform-

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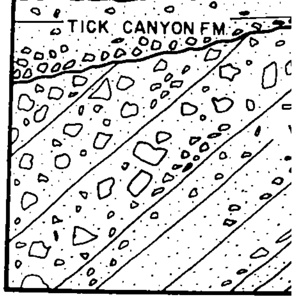

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ck by a widely exposed unconformity that predates the Barstow formation (Woodburne et al., 1982). As seen in Fig. 6, this hiatus from 19 to 16 m.y. ago bridges the time of Mendocino fracture zone passage under the central Mojave block, when uplift would predictably be greatest. Uplift and erosion occurred in other basins as well. The Vasquez, Plush Ranch, and lower Ricardo Formations were eroded and reworked into overlying units (Muehlberger, 1958; Woodburne, 1975), indicating stripping of these basins. The Mint Canyon (Ehlert, 1982) and Caliente Formations (overlying the Vasquez and Plush Ranch, respectively) were deposited by west-flowing streams.

A case history—the Soledad Basin

The Soledad basin (location number 12, Fig. 3) illustrates many features of the fracture-zone model. This basin has been carefully mapped (Muehlberger, 1958) and sampled for paleocurrent and paleomagnetic studies (Bohannon, 1975; Terres et al., 1981). Generalized stratigraphy of the Soledad basin, from Muehlberger (1958), is given in Fig. 7. The oldest widely exposed Tertiary unit is the Vasquez Formation, which comprises up to 3.75 km of nonmarine sandstone, conglomerate, breccia, and mafic volcanic flows. The Vasquez lies nonconformably on the igneous and metamorphic basement of the San Gabriel Mountains, and dips steeply to the south and southwest. Mafic flows at the base of the Vasquez have been dated at 23.9, 24.9 and 20.2 m.y. (Crowell, 1973; Woodburne, 1975). The Vasquez is overlain in angular unconformity by the nonmarine Tick Canyon Formation, which contains late Arikareean vertebrate fossils (Woodburne, 1975). Woodburne notes that this assemblage indicates an age of approximately 21 m.y., and thus the 20.2 m.y. date for the Vasquez is probably erroneous. The Tick Canyon consists of up to 200 m of clay, siltstone, sandstone, and conglomerate, derived in large part from erosion of the underlying Vasquez. The nonmarine Mint Canyon Formation of middle to late Miocene age disconformably caps the Tick Canyon, and lies directly on the Vasquez where the Tick Canyon is absent.

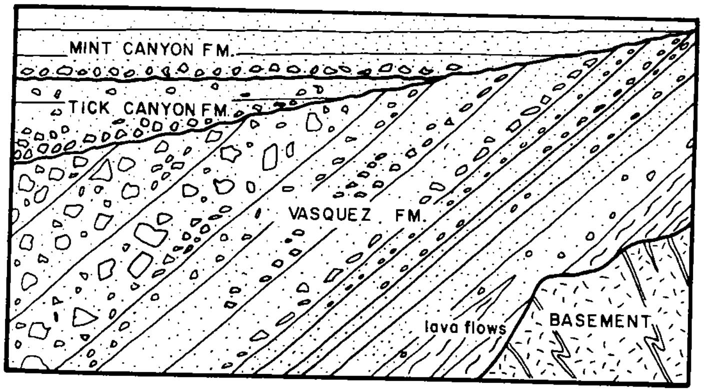

Fig. 7. Schematic stratigraphy of the Soledad basin, from Muehlberger (1958).

The Vasquez coarsens noticeably toward the top (Fig. 5c), and most of the coarse layers, including several breccia sheets, were derived from the south. Bohannon (1975, p. 78) found that the Vasquez "is mostly sandstone and siltstone at its base, but coarsens upward and is conglomeratic about mid-section. Higher in the section, conglomerate is the predominant lithology; quartz diorite clasts increase in percentage to the top of the section, where there is a coarse monolithologic breccia of them with clasts as large as 5 m. Pebble imbrication data show transport from due east to west about mid-section, with a uniform shift to transport from nearly south to north at the top of the section." The breccia sheets were probably deposited at the bases of north- to northwest-facing fault scarps. Paleomagnetic studies (Terres et al., 1981) suggest that the Vasquez has been rotated clockwise about 35° since deposition, so the northward transport directions recorded in the Vasquez were probably northwestward in the early Miocene. Paleocurrent studies of the overlying Mint Canyon formation indicate westward sediment transport (Ehlert, 1982).

The sequence of events recorded in the Soledad basin matches the sequence predicted by the fracture-zone model, including:

(1) Westward drainage and deposition of normal fluvial sediments when the fracture zone was to the south (lower Vasquez).

(2) Sudden coarsening of sedimentation, including emplacement of extremely coarse breccias and landslide deposits, and shift to northward sediment transport when the fracture zone reached the vicinity of the basin (upper Vasquez).

(3) Sudden uplift, tilting, and erosion of the previously deposited sediments followed by their redeposition (Tick Canyon) as the fracture zone moved under the basin.

(4) Reestablishment of westward drainage and deposition of normal fluvial sediments (Mint Canyon) as the fracture zone moved to the north.

The age constraints on the Vasquez and Tick Canyon Formations indicate that the first three events of this sequence took place within about 2 or 3 m.y.

Summary

Consistent patterns appear in the Oligocene–Miocene geology of all the southern California basins we reviewed. Late Oligocene–early Miocene sediments were deposited on eroded pre-Tertiary basement or early Tertiary sedimentary rocks. The onset of sedimentation was later in the Mojave block than in the Transverse Ranges and Salinian block because the Mojave block was farther north than these areas during the early Miocene, before major right slip on the San Andreas fault. The coarsest sediments in most basins were deposited in a fairly narrow time interval closely corresponding to the time of passage of the Mendocino fracture zone under each basin. This coarsening suggests that maximum relief was developed at this time.

Paleocurrent directions in late Oligocene–early Miocene continental sediments are remarkably consistent. Most of the continental basins we investigated had

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northward drainage at some time within this interval; although some basins also had southward drainage, none had significant westward or eastward drainage. North-prograding alluvial fans and north-flowing streams typified sedimentation during this period. Down-to-the-north movement on east–west faults probably played a significant part in the evolution of some basins; this is suggested by breccias shed north from east-west faults in several basins.

Later Miocene sediments differ significantly from the earlier Miocene and Oligocene deposits. They are generally unconformable on tilted and eroded early Miocene, and in some areas contain clasts reworked from the underlying sediments. Late Miocene clastic rocks are generally finer-grained than the rocks they overlie, and were deposited by west- and east-flowing streams.

DISCUSSION

The fracture-zone sedimentary-tectonic model is consistent with regional geology and detailed basin geology in all the major structural blocks of southern California. However, there are significant differences in detail between basins which the fracture-zone model alone cannot explain. The structural and sedimentary development of any basin depends to a large extent on local geology, so it is important to consider possible local effects when evaluating any model. Preexisting paleotopography could also continue to influence sedimentation after uplift over the fracture zone occurred. A source area north of a basin could maintain its identity if it were too high for its south-facing transport surface into the basin to be reversed by northward tilting resulting from deformation of the basin during fracture-zone passage.

Pre-Tertiary crustal history would be a critical factor determining the morphology of basins initiated or modified by bending over the fracture-zone scarp. Even with stress-regime changes imposed by this flexure, structural history would cause deformation to occur preferentially along existing crustal anisotropies and the orientations of the resulting structures would not necessarily be east–west as predicted by the simplest-case assumptions of the model. This possibility is illustrated by the Nacimiento fault in the Salinian block; the fault trends north-northwest but experienced down-to-the-northeast slip accompanied by breccia emplacement about 25 m.y. ago (Vedder and Brown, 1968; Blake, 1982). The properties of the crust in any area would, in part, determine whether it deformed by faulting or flexure as it rode over the fracture-zone scarp. Both structural configuration and crustal density would influence basin subsidence rates, controlling sediment thickness and facies.

The absence of Tertiary sedimentary rocks in the southern Mojave block is probably a result of differences in crustal structure between the central and southern Mojave. Sedimentation in the central Mojave occurred primarily in the Barstow–Bristol trough (Gardner, 1980; Glazner, 1981b), where localization of volcanism, sedimentation, and ore deposits suggests control by structural discontinuities.

CONCLUSIONS

Conclusions of this study are:

(1) Most sedimentary basins in southern California for which we could obtain sufficient data show evidence for north-directed paleocurrents near the time that the Mendocino fracture zone is predicted to have passed under the area.

(2) Many sedimentary basins began receiving abundant sediments at the predicted time of passage of the fracture zone, and preexisting basins were deepened or deformed.

(3) Coarse clastic sedimentation, including deposition of major megabreccias, coincided with the time of fracture-zone passage.

(4) Many sedimentary sequences show evidence for uplift and erosion shortly after the predicted time of passage of the fracture zone.

The model presented above can be tested and refined by further work in unstudied areas of the southwestern United States. In particular, sedimentation in western Arizona (Eberly and Stanley, 1978) and southeastern California (Olmsted et al., 1973) should conform to the model. Fluvial and lacustrine deposits in Arizona are younger in the north than in the south (Nations et al., 1982), as predicted by the model, but the ages of the basins are not well enough constrained to allow adequate testing.

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